Regionally resolved, observationally constrained marine low cloud feedbacks

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Background and Motivation

- Large-scale meteorological forcing parameters control marine boundary layer properties and current-climate low cloud variability.

- If we know the sensitivity of low cloud radiative flux to these cloud-controlling factors from current-climate variability, and if we know how these factors will change in response to climate warming, we can predict the marine low cloud feedback.

- A series of studies* applied this method to observationally constrain cloud feedbacks over large areas in the tropics. They predict a consensus estimate of the local tropical low cloud feedback of **1±0.7 W m^{-2} K** (Klein et al. 2017).

*(Qu et al. 2015; Zhai et al. 2015; Myers and Norris 2016; Brient and Schneider 2016; McCoy et al. 2017)

We observationally constrain the low cloud feedback and its pattern over the global oceans and quantify its contributions from stratocumulus, trade cumulus, regions of tropical ascent, and middle latitudes.

Using Satellite Cloud Observations to Constrain the Feedback

We decompose the low cloud feedback at each 5° x 5° ocean grid box between 60°S and 60°N as

$$\frac{dR}{dT} = \sum \frac{\partial R}{\partial x_i} \frac{dx_i}{dT}$$

$\frac{\partial R}{\partial x_i}$ observed sensitivity of low cloud radiative flux R to a perturbation in some cloud-controlling factor x_i when all other factors are held fixed (poster and in prep paper by **Ryan Scott and co-authors**)

$\frac{dx_i}{dT}$ change in cloud-controlling factor per degree global mean warming T, estimated as ensemble mean of CMIP5 abrupt4xCO2 simulations

Using Satellite Cloud Observations to Constrain the Feedback

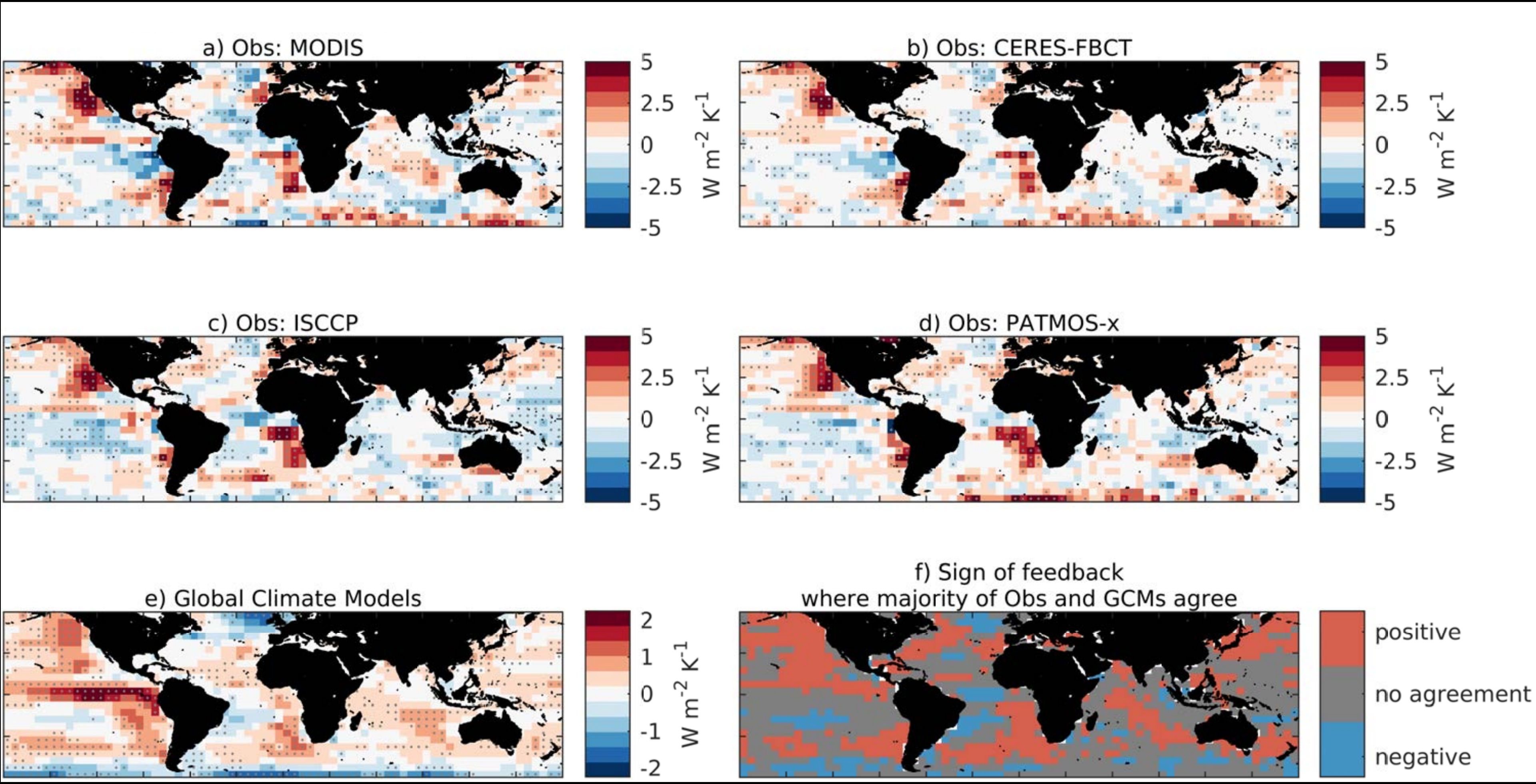
Complete set of cloud-controlling factors x_i includes (from reanalysis)

- sea-surface temperature (SST)
- estimated inversion strength (EIS)
- horizontal surface temp. advection
- free-tropospheric relative humidity
- free-tropospheric subsidence
- near-surface wind speed

Estimate low cloud radiative anomalies by application of kernels to cloud fraction

- MODIS, ISCCP, PATMOS-x, CERES-FBCT

Results: Observationally Constrained Low Cloud Feedback



Obs: Positive feedback in eastern ocean basins (up to 5 W m^{-2} K^{-1}) and middle latitude North Pacific; weaker feedback in trade cumulus regions.

GCMs (7 CMIP5 models): Qualitatively similar characteristics.

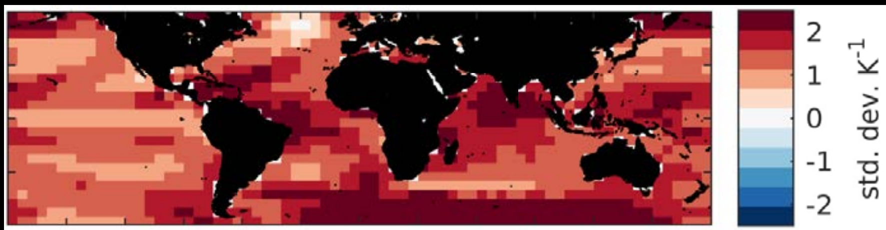
Which cloud-controlling factors drive this feedback?

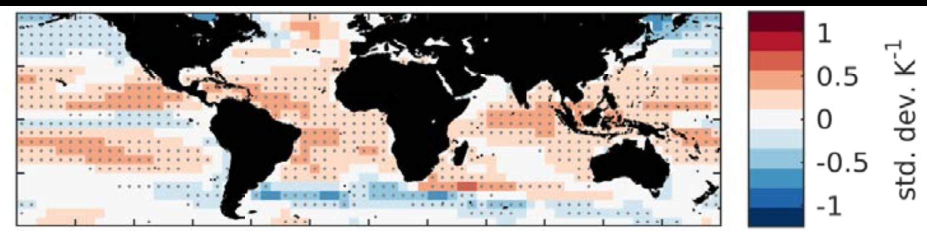
Dominant Feedback Components: SST and Est. Inv. Strength

$\frac{dSST}{dT}$

Due to 4xCO2

$\frac{d\mathrm{EIS}}{dT}$

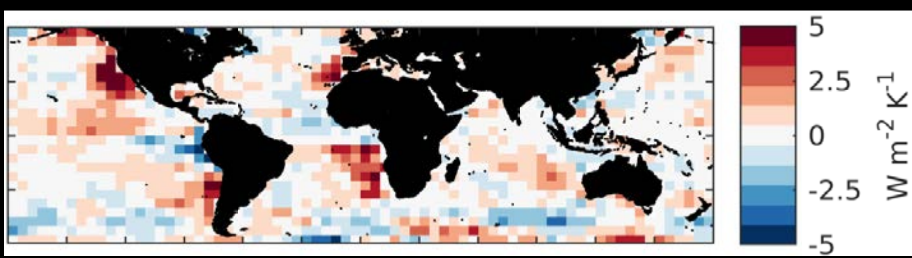


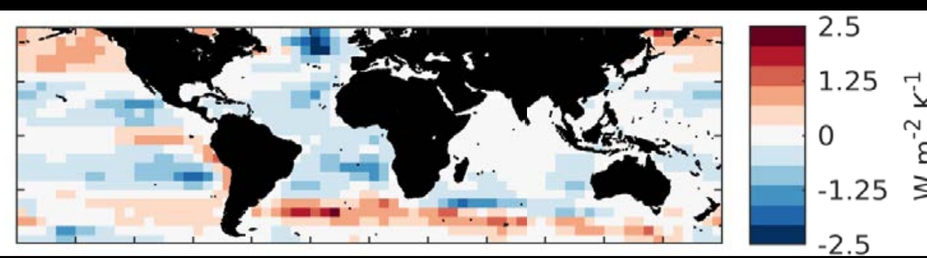


$\frac{\partial R}{\partial SST}\frac{dSST}{dT}$

Feedback component

$\frac{\partial R}{\partial \mathrm{EIS}}\frac{d\mathrm{EIS}}{dT}$





Strong positive SST-driven feedback in eastern ocean basins

Positive EIS-driven feedback in extra-tropics

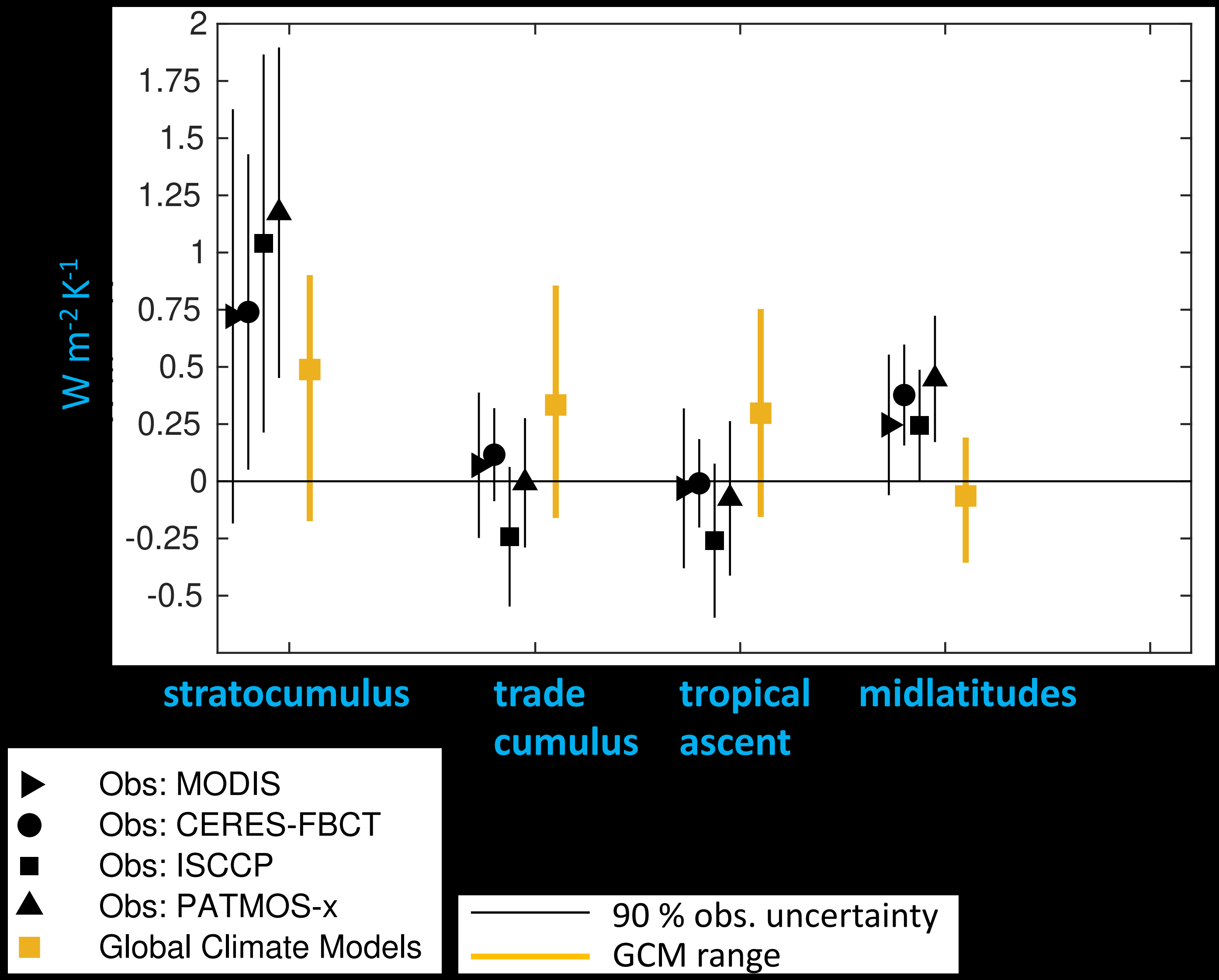
Negative EIS-driven feedback in tropics

Regime-partitioned cloud feedbacks

(defined using climatological EIS, ω_{700})

Regime-averaged Marine Low Cloud Feedbacks

SW+LW

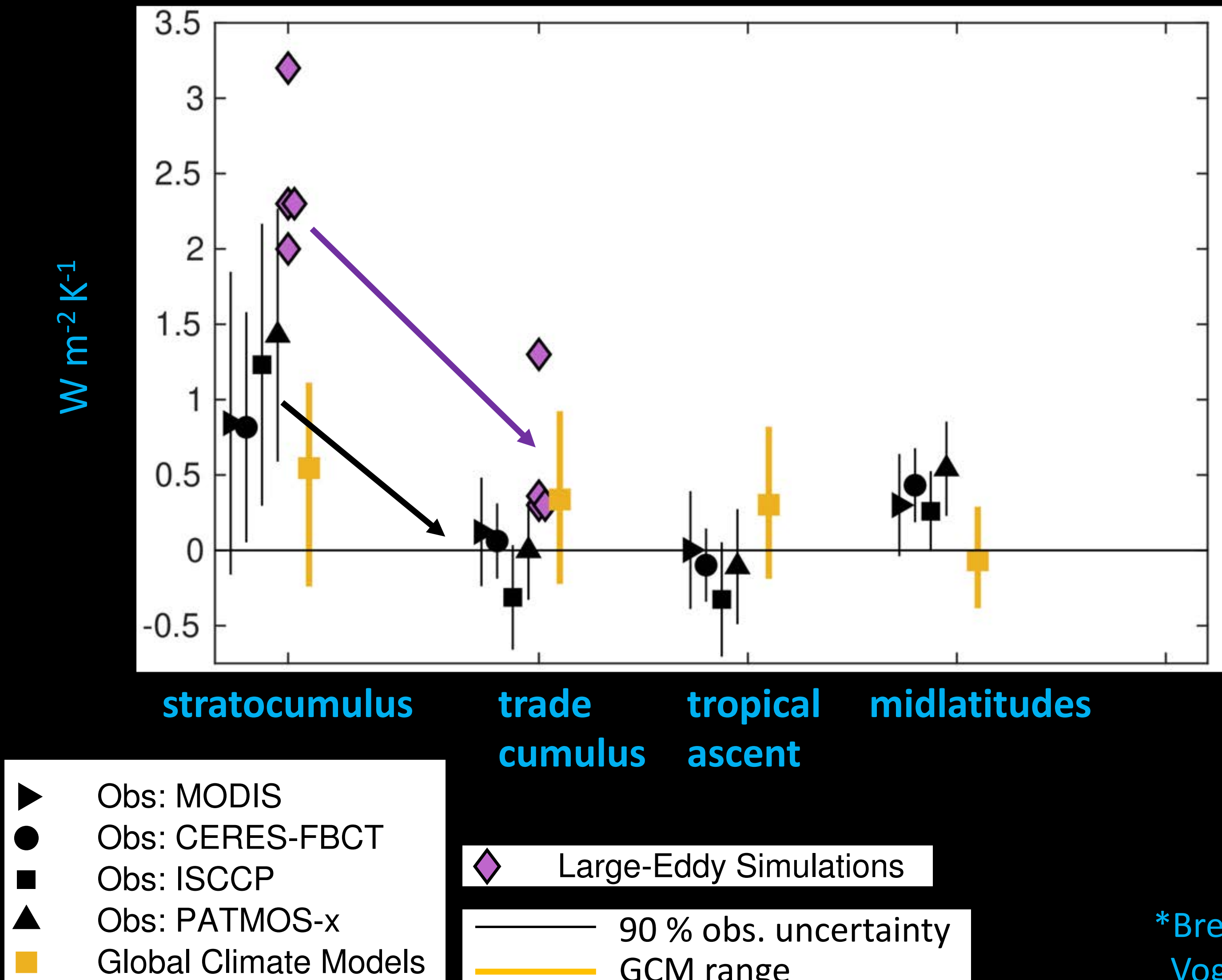


Positive obs. constrained stratocumulus & midlatitude cloud feedbacks (from amount *and* optical depth)

Near-zero trade cumulus feedback, consistent with LES

Regime-averaged Marine Low Cloud Feedbacks

SW only + LES*



Positive obs. constrained stratocumulus & midlatitude cloud feedbacks (from amount *and* optical depth)

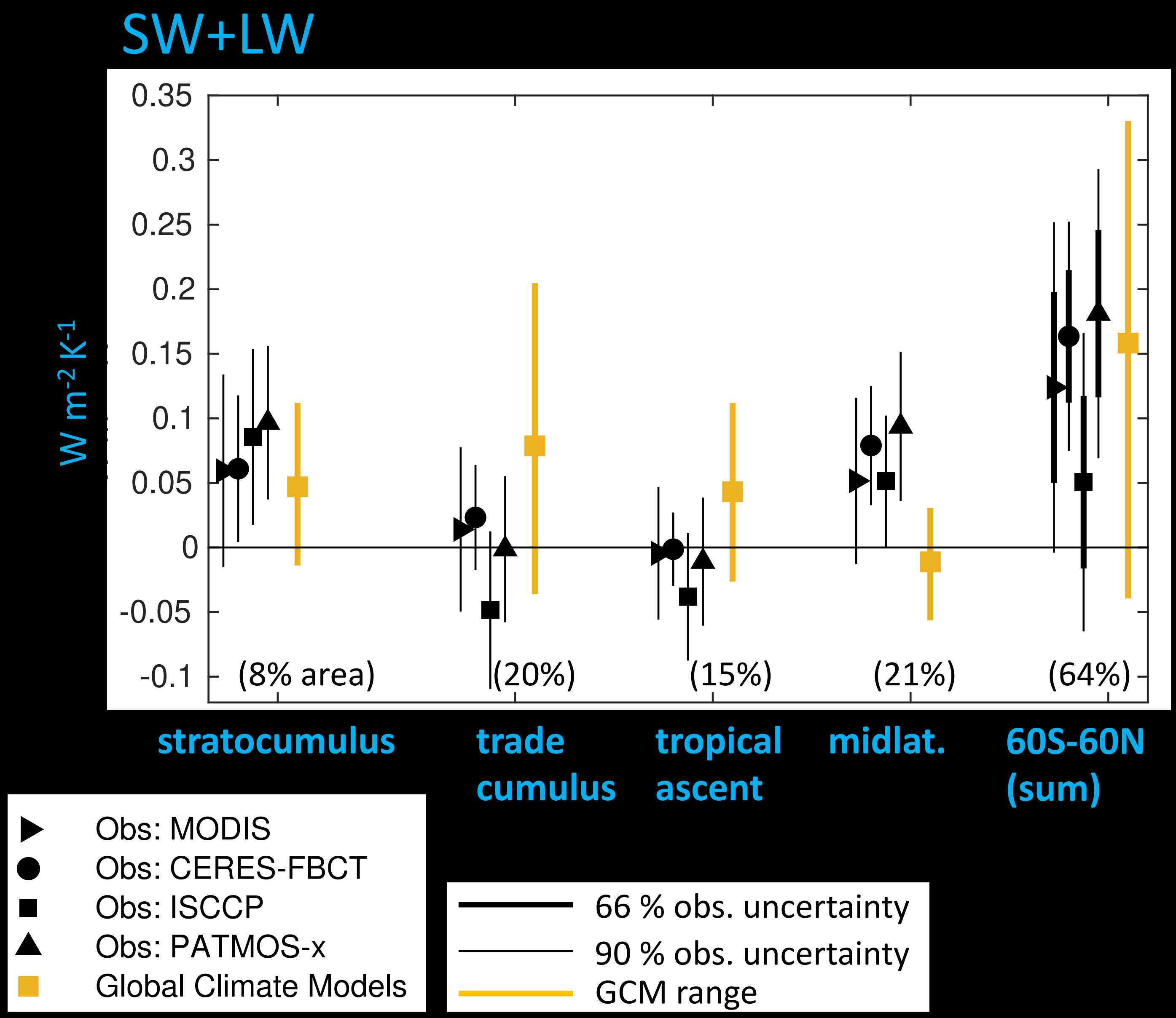
Near-zero trade cumulus feedback, consistent with LES

*Bretherton et al. 2015; Vogel et al. 2016; Tan et al. 2017

Scaled cloud feedbacks

(contributions to global mean)

Scaled Marine Low Cloud Feedbacks



Stratocumulus & midlatitude cloud feedbacks provide similar contributions to global mean

Positive 60S-60N feedback

Conclusions and New Insights

Robust observational evidence that:

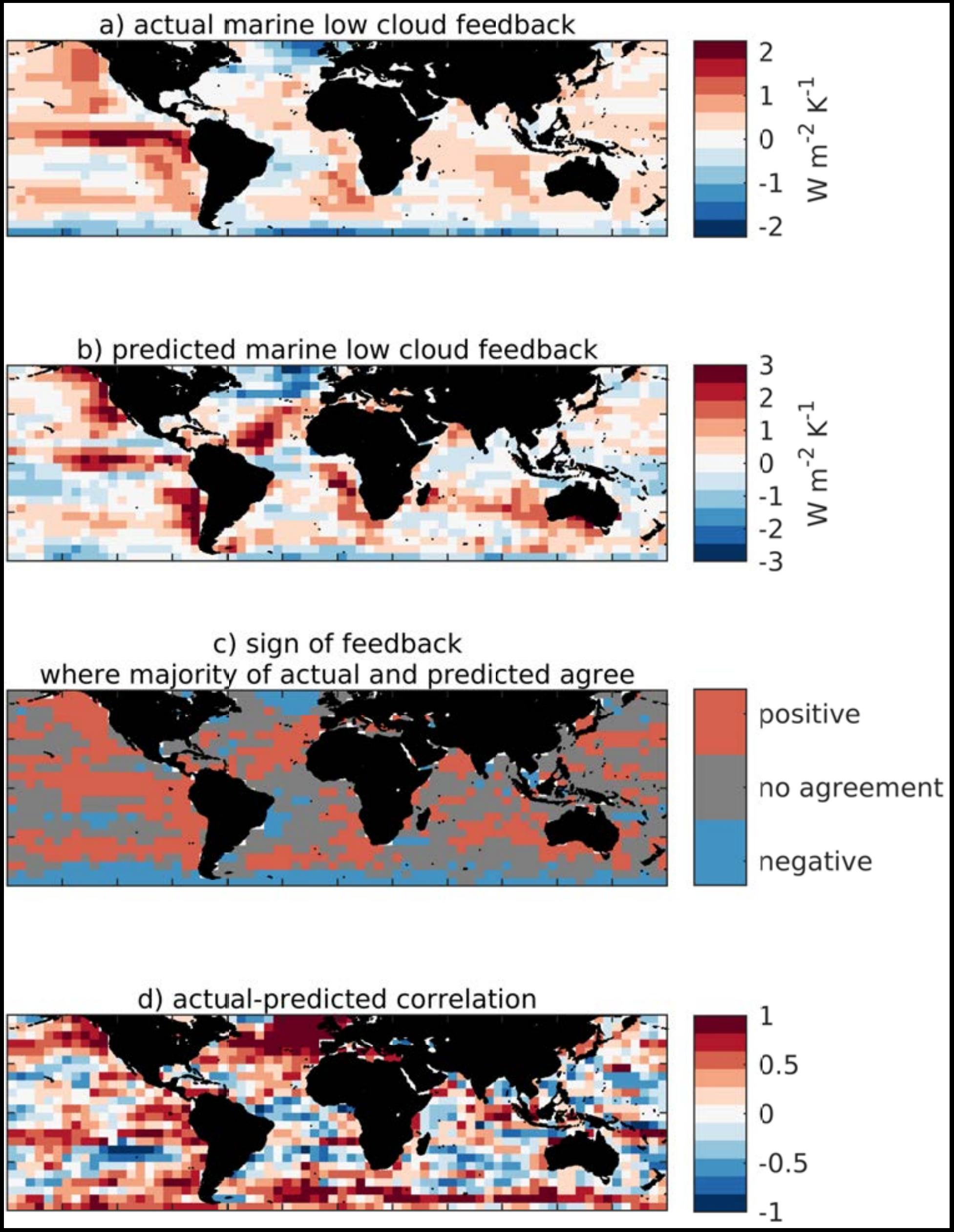
- Stratocumulus clouds in eastern oceans and middle latitude low clouds → less extensive and optically thinner in response to climate warming

- Positive stratocumulus and midlatitude low cloud feedbacks largely driven by SST and EIS changes

- Tropical low cloud feedbacks are non-uniform (consistent w/LES)

Extras slides / potpourri

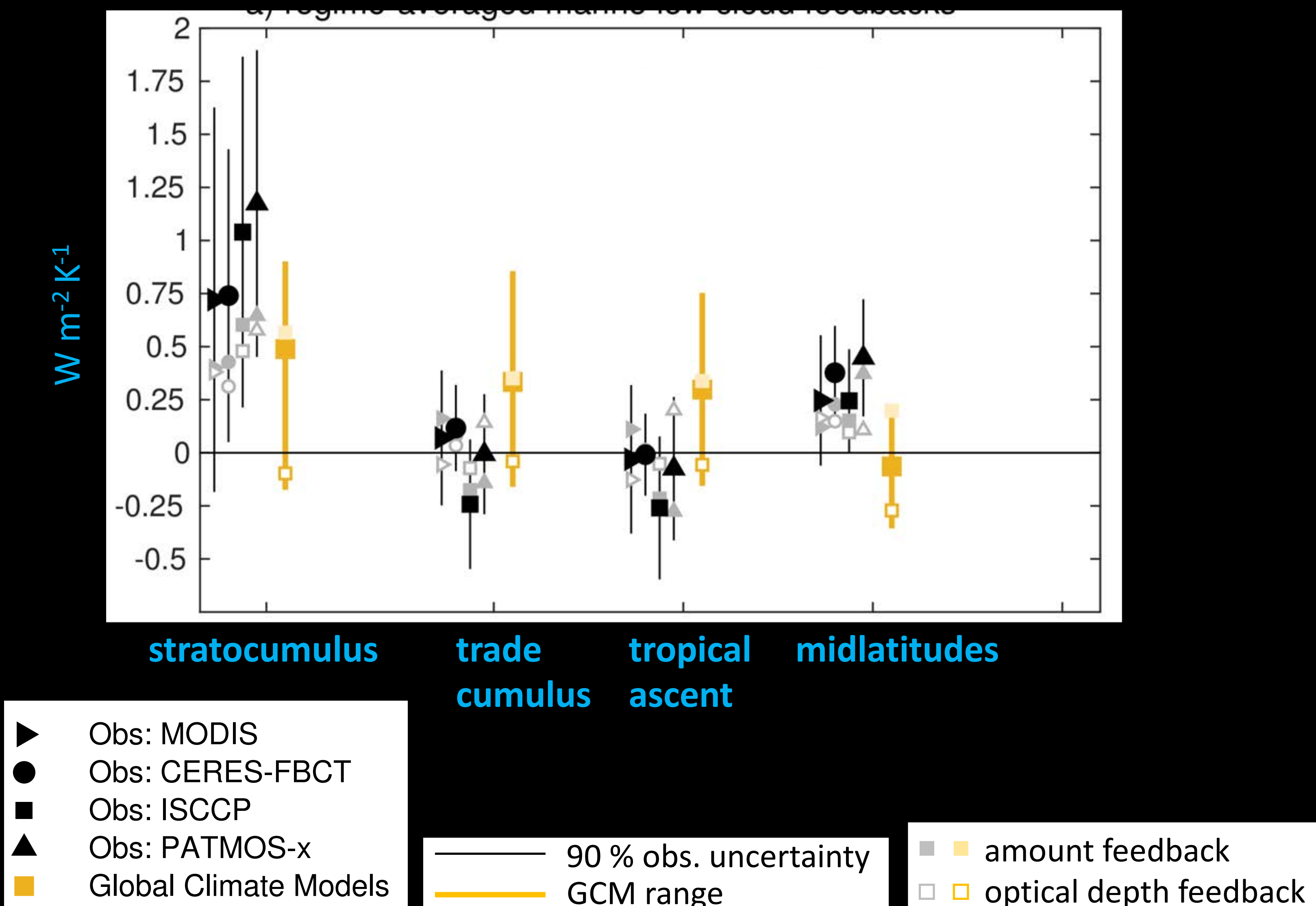
Performance of the regression model



Regime-averaged Marine Low Cloud Feedbacks

+ amount and optical depth components

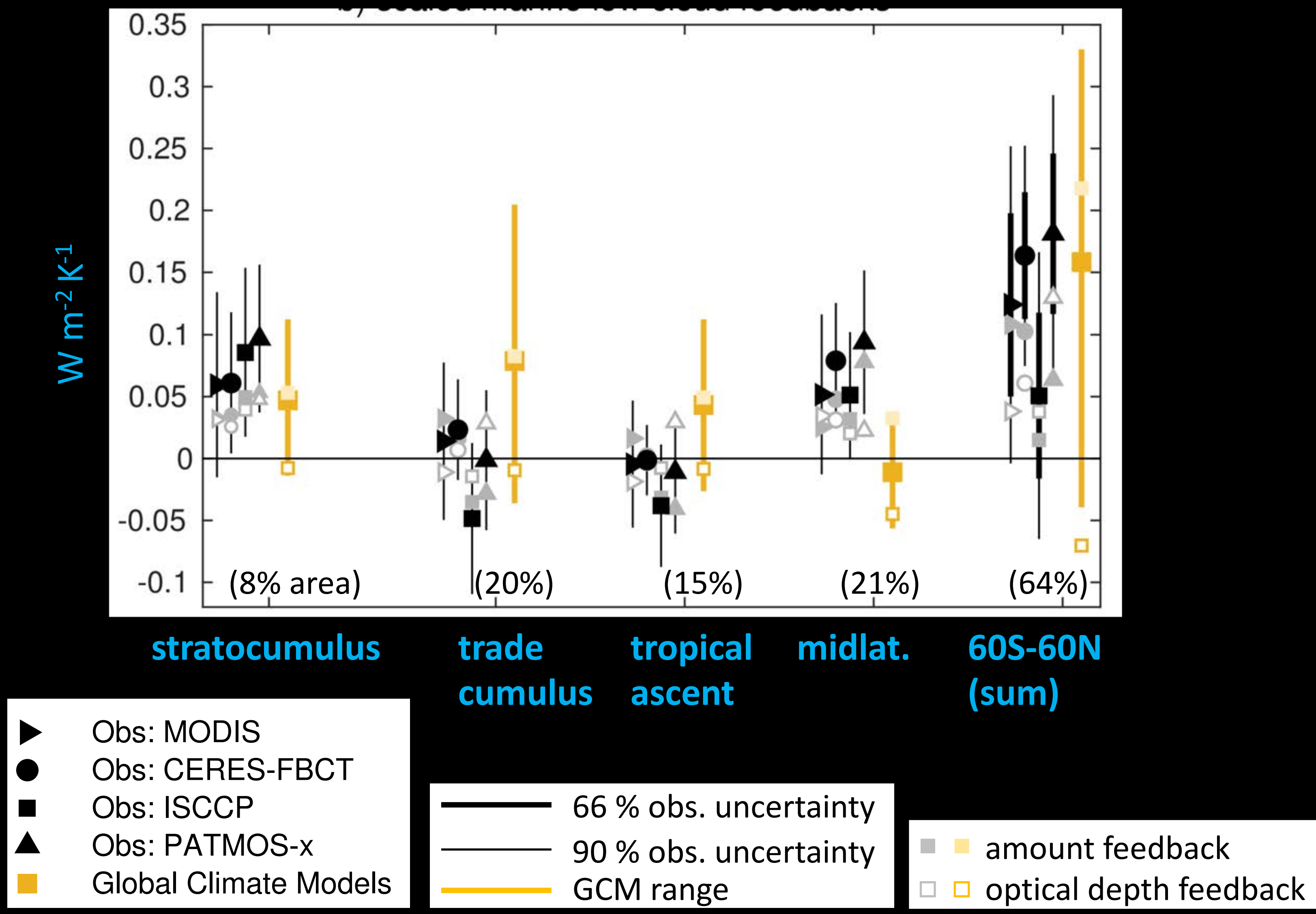
SW+LW



Scaled Marine Low Cloud Feedbacks in Obs. and GCMs

+ amount and optical depth components

SW+LW



Using Satellite Cloud Observations to Constrain the Feedback

How do we estimate low cloud radiative anomalies R' globally?

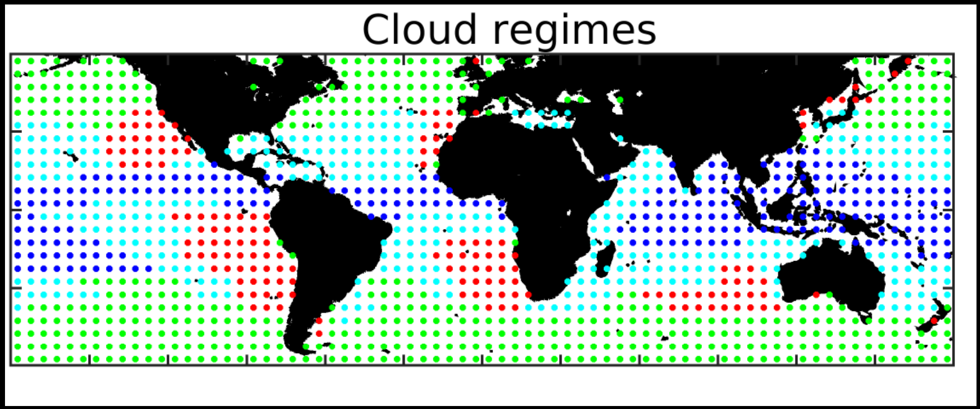
For each month and grid box, we apply Zelinka cloud radiative kernels $k = k(\tau, p)$ to passive satellite-retrieved low-level (>680 hPa) cloud fraction $L = L(\tau, p)$ normalized by the fraction F of the grid box unobscured by higher-level clouds:

$$R' = \bar{F} \sum_{p=1}^{2} \sum_{\tau=1}^{T} k(L/F)'$$

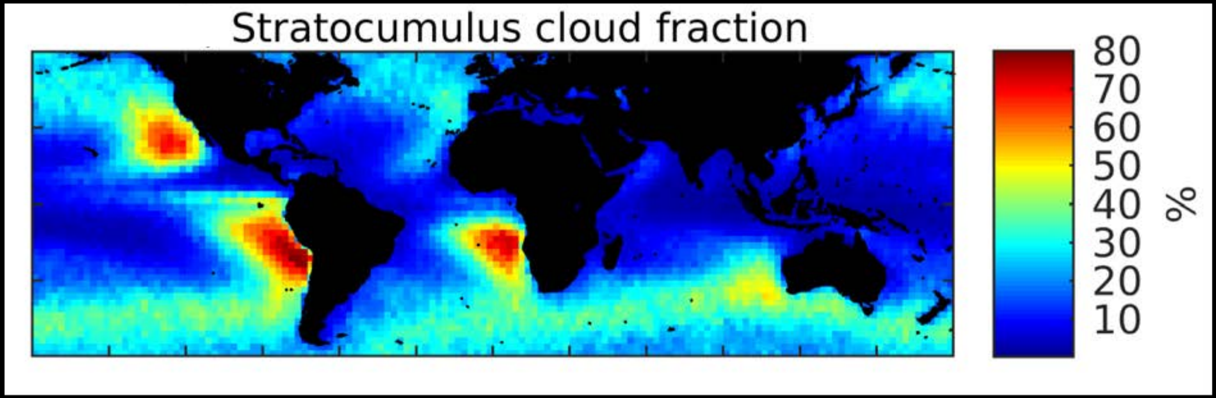
Cloud fraction histograms from **MODIS (TERRA+AQUA), ISCCP, PATMOS-x**

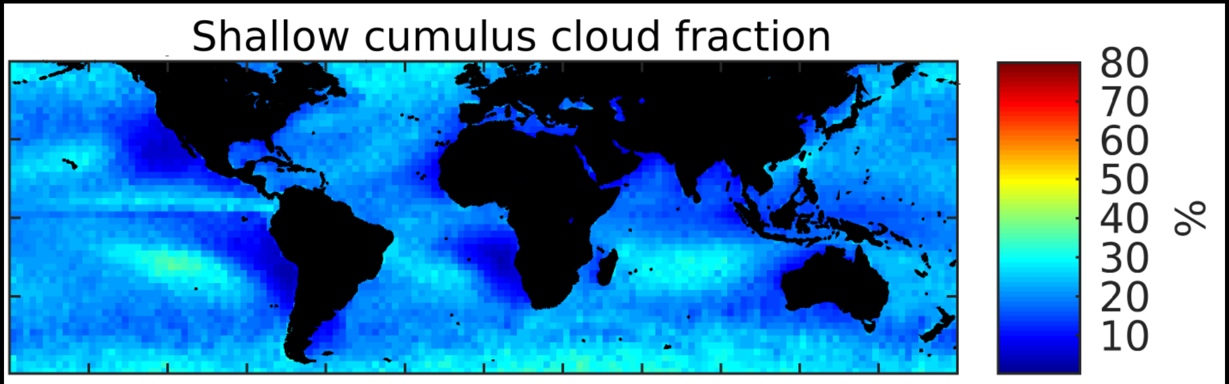
These fluxes are exclusively due to changes in unobscured low-level clouds and not due to changes in the obscuration of low clouds by higher-level clouds.

We apply a similar equation to the new **CERES Flux-by-Cloud-Type dataset**, which provides monthly radiative flux and cloud fraction for 42 cloud types constrained by CERES-EBAF TOA flux.



Stratocumulus
(strong subsidence, sharp inversion)
Trade cumulus
(weak subsidence, weak inversion)
Tropical ascent
Midlatitudes
(variable ω_{700}, sharp inversion)





Cumulus And Stratocumulus CloudSat-CAlipso Dataset (CASCCAD; Cesana et al. 2019)